

OBSERVATIONS OF SOLAR FLARE PHOTON ENERGY SPECTRA
FROM 20 KEV TO 7 MEV

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ABSTRACT

Solar flare photon energy spectra in the 20 keV to 7 MeV range are derived from the Apr. 1, Apr. 4, Apr. 27 and May 13, 1981 flares. The flares were observed with a hard X-ray and a gamma-ray spectrometers on board the Hinotori satellite. The results show that the spectral shape varies from flare to flare and the spectra harden in energies above about 400 keV. Effects of nuclear line emission on the continuum and of higher energy electron bremsstrahlung are considered to explain the spectral hardening.

1. Introduction

The acceleration of electrons and ions during solar flares has been an essential key problem in the study of high energy solar phenomena. Electrons accelerated to the MeV energy range emit radiowaves through synchrotron radiation and hard X-ray and gamma-ray continuum through bremsstrahlung. Solar hard X-rays in the 10 to 200 keV range have been extensively observed, and various problems on the electron acceleration mechanism and the correlation between radiowaves and hard X-rays have been discussed. Most of the hard X-ray spectrum are approximated by a power law spectrum with index of 3.0 to 5.0. However, only a few observations of the photon spectrum extending to gamma-ray energies have been reported. The solar X-rays and gamma-rays were first simultaneously observed from the 4 Aug., 1972 flare (Hoyng et al., 1976; Chupp et al., 1973). The photon spectrum extending to 7 MeV was reported (Suri et al., 1975). The observed spectrum revealed a change in the spectral shape at about 700 keV. Contributions of unresolved gamma-ray lines and new hard component were suggested to explain the spectral change. However, the hard X-ray and gamma-ray spectra were little reported after the observation of the 4 Aug., 1972 flare. It is because of no satellite dedicated to the solar X- and gamma-ray observations. Recently, more data of solar X- and gamma-rays were obtained from SMM and Hinotori observations. These two satellite observations have made it possible to discuss in detail the photon spectrum extending to gamma-ray energies and the hard X- and gamma-ray emission processes. In the present paper, the photon spectra in the 20 keV to 7 MeV range observed from the 1 Apr., 4 Apr., 27 Apr. and 13 May, 1981 flares are presented and the photon spectral shapes are discussed.

2. Observations

The Hinotori satellite is dedicated to solar flare observations and its prime objective is to study high energy flare phenomena in the X- and gamma-ray energies. The hard X-ray spectrometer (8.9 cm dia. x 1 cm thick NaI scintillator) covers the energy range of 17 to 370 keV. The primary data output is a full resolution 7 channel pulse height spectrum every 125 ms (Ohki

et al., 1982). The gamma-ray spectrometer (8.9 cm dia. x 5 cm thick CsI scintillator) covers the energy range of 0.3 - 7 MeV range. The primary data output is a full resolution 128 channel pulse height spectrum every 2 s (Yoshimori et al., 1983a). Some of the Hinotori hard X- and gamma-ray data have been already reported (Ohki et al., 1983; Nitta et al., 1983; Yoshimori et al., 1983b). However, no photon spectrum in the 20 keV to 7 MeV range has been presented. The photon energy spectra from the 1 Apr., 4 Apr., 27 Apr., and 13 May, 1981 flares are presented here. Time histories of these flares were described (Yoshimori, 1985).

The 1 Apr., 1981 flare occurred at 0134 UT and lasted for about 26 min. The flare revealed the gradual time history. The $H\alpha$ importance and the GOES class were 2B and X2.3, respectively. The photon spectrum observed in the interval of 0144:57 to 0156:40 UT is shown in Fig. 1. The photon spectrum is approximated by a power law spectrum with index of 3.75 in energies below about 300 keV, but the spectrum reveals a hardening in energies above about 400 keV.

The 4 Apr., 1981 flare occurred at 0502 UT and lasted for about 80 s. The flare revealed the impulsive time history. The $H\alpha$ importance and the GOES class were 2B and X1.9, respectively. The photon spectrum observed in the interval of 0502:17 to 0503:05 UT is shown in Fig. 2. The photon spectrum is approximated by the power law spectrum with index of 3.28 or an exponential thermal spectrum with temperature of 7.28×10^8 K in energies above 300 keV. A hard spectral component is apparent in energies above 400 keV.

The 27 Apr., 1981 flare occurred at 0750 UT and lasted for about 30 min. The flare revealed the gradual and multi-peak time history. The $H\alpha$ importance was not recorded, but the GOES class were 3B. The photon spectrum observed in the interval of 0810:05 to 0814:21 UT is shown in Fig. 3. The photon spectrum is approximated by the power law spectrum with index of 4.00 in energies below 300 keV. The hard spectral component is apparent in energies above 400 keV.

The 13 May, 1981 flare occurred at 0412 UT and lasted for about 18 min. The flare revealed the gradual time history with small increase. The $H\alpha$ importance and the GOES class were 3B and X1.5, respectively. The photon spectrum observed in the interval of 0419:42 to 0428:13 UT is shown in Fig. 4. The photon spectrum is approximated by the power law spectrum with index of 3.22 in energies below 300 keV. The spectrum reveals the hardening in energies above 400 keV.

3. Discussion

The Hinotori satellite hard X- and gamma-ray observations reveal that the photon spectral shapes do not much vary from flare to flare. The power law spectral indices in energies of the 20 to 370 keV range between 3.22 and 4.00, which is consistent with ones observed previously. These power law photon spectra have been interpreted in terms of electron bremsstrahlung. Further, the present results indicate that the spectral hardening occurs at about 400 keV. This spectral hardening seems to be a common characteristics for the gamma-ray flares. It is known that the instrumental effect sometimes cause a spectral bending. However, such instrumental effect is possibly rejected because the spectral analysis in the 20 to 700 keV range has been correctly made for the 7 Oct. and 14 Oct., 1981 flares (Nitta et al., 1983), and the SMM observations also have revealed the similar spectral hardening for the 4 June and 7 June, 1980 flares (Orwig et al., private communication).

Various physical processes which could produce such observed hardening are

considered. Such processes are (1) the effect of observed nuclear gamma-ray line emission on the continuum and (2) the significant contribution of higher energy electron bremsstrahlung. The effect of gamma-ray line emission of positron annihilation at 511 keV, of prompt deexcitation lines of Ne at 1.64 MeV, Mg at 1.36 MeV, Si at 1.78 MeV and Fe at 0.84 and 1.25 MeV and of neutron capture line at 2.22 MeV may be able to explain to some degree the spectral hardening in energies above about 400 keV. The possibility of higher energy electron bremsstrahlung is also considered (Suri et al., 1975). The observed photon spectra probably can not be explained by a population of electrons with a single power law index. Another population of electrons with a harder spectra in energies above a few hundred keV, should be needed to explain the observed spectral hardening. The similar spectral hardening has been reported in large flares such as the 4 Aug., 1972 flare (Suri et al., 1975). The observed spectral hardening represents a characteristics of particle acceleration process in solar flare. The effects of gamma-ray line emission and of higher energy electron bremsstrahlung will be in detail evaluated in near future.

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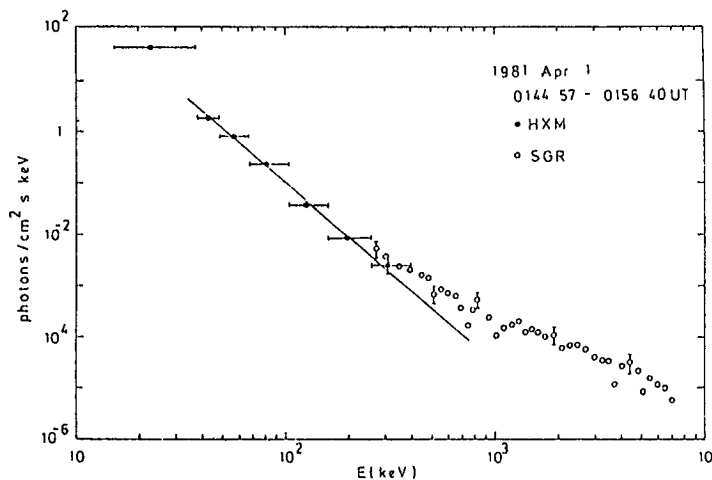


Fig. 1

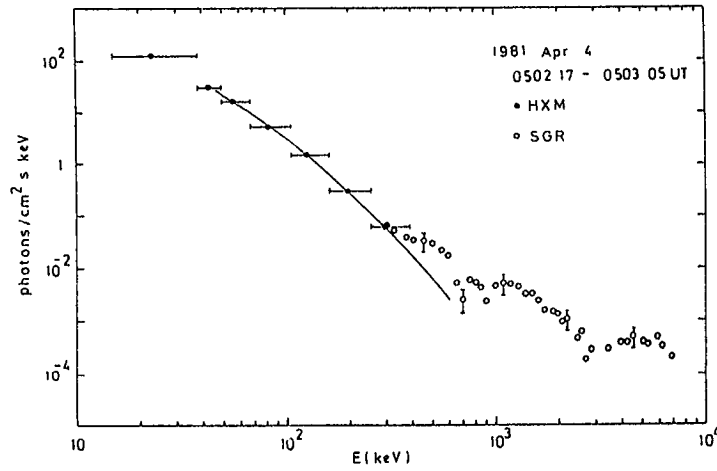


Fig. 2

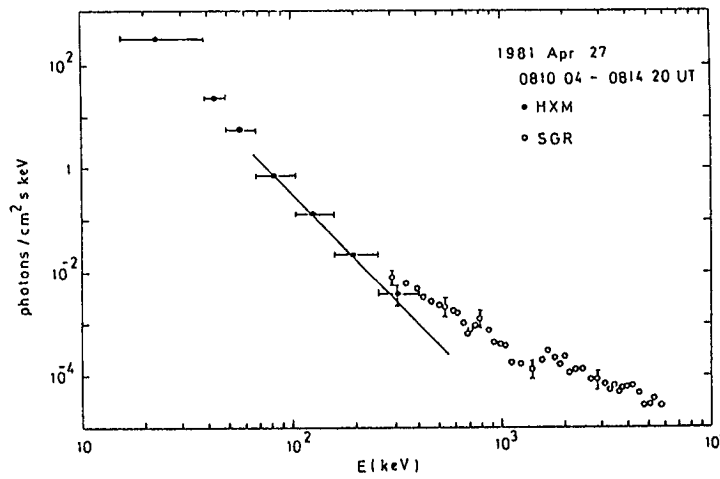


Fig. 3

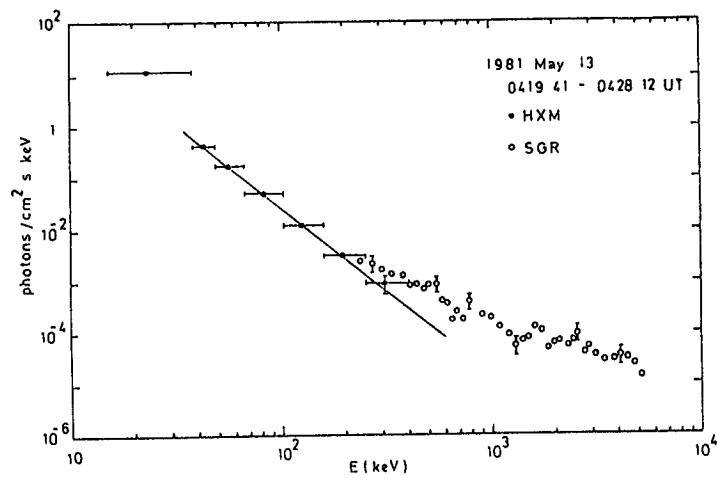


Fig. 4